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A BROADBAND TOWED LINE ARRAY WITH
SPATIAL DISCRIMINTION CAPABILITIES

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN THAT (1) KIM C. BENJAMIN and (2) KENNETH M. WALSH, citizens of the United States of America, employees of the United States Government, and residents of (1) Portsmouth, County of Newport, State of Rhode Island, and (2) Middletown, County of Newport, State of Rhode Island, have invented certain new and useful improvements entitled as set forth above of which the following is a specification:

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3 A BROADBAND TOWED LINE ARRAY WITH
4 SPATIAL DISCRIMINATION CAPABILITIES

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6 STATEMENT OF GOVERNMENT INTEREST

7 The invention described herein may be manufactured and used
8 by or for the Government of the United States of America for
9 governmental purposes without the payment of any royalties
10 thereon or therefor.

11

12 BACKGROUND OF THE INVENTION

13 (1) Field of the Invention

14 This invention generally relates to a broadband, towed line
15 array with spatial discrimination capabilities. More
16 particularly, this invention relates to towed line array
17 technology that relies on simple monopole sensors typically
18 operating in a receive mode only and utilizing a novel modular
19 sub-array arrangement.

20 (2) Description of the Prior Art

21 Several underwater sonar applications exist for steered
22 directional acoustic beams. Although the current towed systems
23 provide spatial discrimination in the direction of tow, a left
24 right ambiguity exists due to the omni-directional sensors
25 employed. Given the orientation of the array in revolution, a

1 directional sensor would resolve this ambiguity and provide
2 essentially three-dimensional spatial discrimination.

3 Typical sensors used in today's towed line arrays consist of
4 solid piezoceramic spheres or cylinders. However, in some
5 special cases they consist of fiber optic cables wound onto
6 mandrels or miniature flextensional transducers. In any case,
7 the element dimensions are small compared to the acoustic
8 wavelength, and thus these sensors operate below their first
9 mechanical resonance.

10 The following patents, for example, disclose towed arrays,
11 but do not disclose a modular sub-array such as that taught in
12 the current invention which may be assembled into a more
13 comprehensive towed array.

14 U.S. Patent No. 4,222,114 to Rolleigh et al.;

15 U.S. Patent No. 4,271,490 to Minohara et al.;

16 U.S. Patent No. 4,766,575 to Erlich et al.;

17 U.S. Patent No. 4,866,682 to Uchihashi et al.; and

18 U.S. Patent No. 6,255,761 to Benjamin.

19 Specifically, Rolleigh et al. disclose a cylinder array
20 radiator that reduces the intensity of energy radiated in
21 undesirable directions. The radiator is constructed so that
22 vertical staves placed on the face of a cylinder are staggered in
23 the vertical direction by a predetermined distance to cancel
24 energy in the undesirable directions.

1 The patent to Minohara et al. discloses an ultrasonic
2 detection system having an array of ultrasonic transducers that
3 are uniformly closely disposed relative to each other such that
4 the active surfaces for transmission or reception are maintained
5 on a straight or curved line. The transducers form radiation or
6 reception beams in a specific direction. Beam orientation is
7 accomplished by selecting a group of transducers from the array
8 and/or respectively applying appropriate phase-shifts to the
9 signals to be fed to each of the transducers, or to the signals
10 produced from each of the transducers. Shields are maintained
11 between two adjacent transducers for suppression of sidelobes.

12 Ehrlich et al. disclose a cylindrical array employing
13 rectangular planar array segments which extend in the axial
14 direction when assembled on a cylindrical conducting plate having
15 flat longitudinal portions to which the planar array segments are
16 attached. Each planar array segment comprises two columns of
17 planar transducer elements with each column extending in the
18 axial direction of the cylinder. The acoustic center of each
19 transducer lies on the circumference of a right circular
20 cylinder. The acoustical requirements of a cylindrical array are
21 satisfied to allow multiple beams to be formed with a minimum of
22 complexity and with the same versatility as in the curved array
23 segment cylindrical array embodiment.

24 Uchihashi et al. disclose an ultrasonic device comprising a
25 plurality of transducer elements arranged in rows and columns and

1 acoustic insulation material maintained between each two adjacent
2 rows of transducer elements. The ultrasonic device comprises (i)
3 a plurality of rows of the transducer elements, each row being
4 disposed on an imaginary circle, (ii) a plurality of circular
5 plates each supporting one of said rows, and (iii) spacers for
6 spacing adjacent plates of the plurality of plates at a
7 predetermined space interval, thereby forming a cylindrical
8 array.

9 The patent to Benjamin discloses a piezoelectric composite
10 transducer and method for making the same. A block of
11 piezoelectric material has a common base and a plurality of
12 uniform-length rods extending from the common base in a parallel
13 spaced-apart fashion to define an array. A first surface region
14 is defined at outboard ends of the rods and a side region is
15 defined about the periphery of the array. Electric conductors
16 extend through the side region, are routed parallel to the first
17 surface region, and are then led substantially parallel to the
18 rods to the first surface region. Spaces between the rods are
19 filled up to the first surface region with a viscoelastic
20 material. The common base of the block is then removed such that
21 a second surface region parallel and opposite the first surface
22 region is defined. Electrodes are deposited at the first surface
23 region to be in contact with the rods and in electrical contact
24 with the electric conductors. A ground electrode is deposited at
25 the second surface region to be in contact with the rods. The

1 resulting piezoelectric composite transducer can be heated and
2 shaped to conform to complex curves.

3 It should be understood that the present invention would in
4 fact enhance the functionality of the above patents by providing
5 a modular sub-array for use with a plurality of other modular
6 sub-arrays. It includes a multi-chamber support structure with
7 an acoustically absorptive hub as a basis for the sub-array.

8

9 SUMMARY OF THE INVENTION

10 Therefore it is an object of this invention to provide a
11 broadband towed line array.

12 Another object of this invention is to provide a towed line
13 array with directional sensors.

14 Still another object of this invention is to provide a towed
15 line array having modular sub-arrays.

16 A still further object of the invention is to provide towed
17 line array in which a multi-chamber support structure defines
18 each modular sub-array.

19 Yet another object of this invention is to provide a towed
20 line array in which discrete sensor elements are housed within
21 the chambers of the multi-chamber support structure for each
22 modular sub-array.

23 In accordance with one aspect of this invention, there is
24 provided a towable array having a multi-chamber support structure
25 and an acoustically absorptive hub formed at a central axis of

1 the multi-chamber support structure. A sensor element
2 substantially conforms in shape to and is selectively secured in
3 each chamber of the multi-chamber support structure and are
4 therefore mechanically isolated from each other. Accordingly,
5 each sub-array module contains multiple sensors along with their
6 associated transmit and receive electronics.

7

8 BRIEF DESCRIPTION OF THE DRAWINGS

9 The appended claims particularly point out and distinctly
10 claim the subject matter of this invention. The various objects,
11 advantages and novel features of this invention will be more
12 fully apparent from a reading of the following detailed
13 description in conjunction with the accompanying drawings in
14 which like reference numerals refer to like parts, and in which:

15 FIG. 1 is an exploded perspective view of a cylindrical sub-
16 array module according to a preferred embodiment of the present
17 invention;

18 FIG. 2A is a top plan view of the cylindrical sub-array
19 module of FIG. 1;

20 FIG. 2B is a top plan view of a sensor element included in
21 cylindrical sub-array module of FIG. 1;

22 FIGS. 3A through 3D are examples of sensor elements of the
23 present invention; and

1 FIGS. 4A through 4D are side perspective views of various
2 sub-array module geometries assembled into larger arrays of
3 modules according to the present invention.
4

5 DESCRIPTION OF THE PREFERRED EMBODIMENT

6 In general, the present invention is directed to a multi-
7 element transducer array packaged in a modular cylindrical
8 configuration suitable for towing underwater, as generally shown
9 at 10 in the exploded perspective view FIG. 1. The modular
10 cylindrical configuration 10 is a sub-array module of plural sub-
11 array modules that may be assembled as shown, by way of example
12 only, in FIGS. 4A through 4D and as will be further described
13 below.

14 Referring to FIGS. 1, 2A and 2B, the modular configuration
15 10 includes a multi-chamber support structure or housing 12
16 surrounding an acoustically absorptive hub 14. The hub 14
17 defines an axial center of the multi-chamber support structure 12
18 and plural chambers 16 thereof are formed to extend radially from
19 the hub 14. In further detail, the multi-chamber support
20 structure 12 will include an upper plate 18 having an opening 20
21 centrally formed therein, a lower plate 22 opposing the upper
22 plate 18 and having an opening 24 centrally formed therein, and a
23 plurality of sectioning walls 26 perpendicular to and spacing the
24 upper and lower plates 18, 22 apart from each other. Each of the
25 plurality of sectioning walls 26 will preferably extend from an

1 outer peripheral edges 18A, 22A of the upper and lower plates 18,
2 22 to an inner peripheral edges 18B, 22B thereof and in
3 conjunction with the centrally formed and aligned openings 20,
4 24. It is at the space defined by the centrally formed and
5 aligned openings 20, 24, and inner edges of the plurality of
6 sectioning walls 26 where the acoustically absorptive hub 14 is
7 located.

8 The multi-chamber support structure 12 is formed of a
9 viscoelastic material so as to provide isolating, waterproofing,
10 and other protective properties to the modular array. Further,
11 the multi-chamber support structure 12 including the upper and
12 lower plates 18, 22, and the plural sectioning walls 26, may be
13 integrally formed as a one-piece construction or assembled
14 together from separate pieces according to the manufacturer.

15 The arrangement of the multi-chamber support structure 12,
16 and particularly the plural sectioning walls 26 thereof, is
17 specifically intended to afford mechanical isolation between
18 individual composite sensor elements 30 within the modular sub-
19 array 10. These composite sensor elements 30 are, by way of
20 example, a plurality of piezoelectric polymer composite elements.

21 A first example of an individual sensor element 30 is shown
22 in FIG. 2B as a piezoelectric element including multiple layers
23 of active piezocomposite material 32, 34, and an electrical
24 isolator 36. Electrodes 38 are formed on the outer 30A and inner
25 30B surfaces of the sensor element 30 using electroplated copper

1 or any other suitable technique known in the art. A structural
2 adhesive 40 is used to join the layered assembly of active layers
3 32, 34 and isolator 36 members together. The structural adhesive
4 40 is also used to bond the individual sensor elements 30 to the
5 support structure 12 at inner surfaces of each chamber 16 as
6 shown by the dotted lines, and to the outer peripheral surface
7 14a of the acoustically absorptive hub 14.

8 Sensor elements 30 are addressed by way of cabling embedded
9 within the piezocomposite substrate. This means of addressing is
10 known in the art and is not intended to form a part of this
11 invention, and therefore will not be described in further detail
12 for the sake of simplicity of this disclosure.

13 Referring now to FIGS. 3A through 3D, there are illustrated
14 various piezoelectric polymer composite sensor element
15 configurations 30, any of which would be suitable for use in the
16 modular sub-array 10 of the present invention. These
17 arrangements are achieved by varying the geometry of the
18 piezoceramic 32, and polymer 36 phases as shown. The
19 illustrations are not intended to limit the particular
20 construction of composite sensor elements 30 of the present
21 invention, but are intended to be illustrative examples only.

22 In addition, there are an extensive number of array or sub-
23 array profiles along the tow direction that will be available to
24 one of ordinary skill in the art, as exemplified by FIGS. 4A
25 through 4D. Note that FIGS. 4A through 4D are viewed in the tow

1 direction. For example, a side view of the modular sub-array 10
2 of FIG. 1 may be cylindrical as in FIG. 4A, conical as in FIG.
3 4B, cylindrical with arcuate outer peripheries as in FIG. 4C, or
4 arcuately increasing and decreasing as in FIG. 4D. The
5 geometries are nearly limitless and may be modified according to
6 end use while still employing the features of a multi-chamber
7 support structure 12 with an acoustically absorptive hub 14, and
8 plural mechanically isolated sensor elements 30 housed therein as
9 set forth above.

10 Unlike conventional towed array designs, the radiating
11 aperture in this case is delineated in both length and
12 revolution. Thus, the sub-array module 10 is capable of
13 providing spatial discrimination (a steered acoustic beam) in
14 three dimensions.

15 The towed array will consist of a plurality of modular sub-
16 arrays 10 having cylindrical geometry. The number of sub-array
17 modules 10 required would depend on the applications, and is
18 limited only by the towing capability of the vehicle. Each sub-
19 array module 10 contains multiple sensors 30 along with their
20 associated transmit and receive electronics.

21 The modular sensor element 30 sizes and shapes can be
22 uniform or made to vary according to the intended application.
23 Additionally each layer within the sensor element 30 may be
24 independently addressed in order to electronically compensate for
25 response variations that are typical when extending the sonar

1 system operation above the element's first thickness mode
2 resonance. Therefore, broadband signals like FM, or phase coded,
3 CHIRPS may be conveyed over a broad frequency range.

4 The disclosed invention provides several major advantages
5 over conventional towed line arrays. These include but are not
6 limited to: a dual transmit/receive operation; three-dimensional
7 spatial discrimination; and broadband operation, which aside from
8 the element's individual layers, may be addressed separately to
9 further extend a sonar system's operational bandwidth.

10 Techniques involving compensation electronics, known to the art,
11 may be employed to extend the layered element response well past
12 the first thickness mode resonance, and integral electronics
13 allow modular sensor design.

14 In view of the above detailed description, it is anticipated
15 that the invention herein will have far reaching applications
16 other than those of towed underwater arrays.

17 This invention has been disclosed in terms of certain
18 embodiments. It will be apparent that many modifications can be
19 made to the disclosed apparatus without departing from the
20 invention. Therefore, it is the intent of the appended claims to
21 cover all such variations and modifications as come within the
22 true spirit and scope of this invention.